Can Robots Accelerate the Learning Curve for Surgical Training? An Analysis of Residents and Medical Students

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Abstract

Surgical traineeship has traditionally been based on a master apprentice model where learning takes place in the operating theatre. This approach has changed over the past few years with greater emphasis on surgical training taking place within the surgical skills laboratory. We developed a high fidelity simulator, the Image-guided Robotic Assisted Surgical simulator (IRAS) with an incorporated robotic guidance feature. The robot system is developed to mimic the process of an experienced surgeon physically holding a trainee's hands to demonstrate manoeuvring of the laparoscopic instruments. We aimed to assess the efficacy of incorporating robotic guidance into this high fidelity surgical simulator. Forty-two participants (13 surgical residents and 29 medical students) were recruited. Participants had one practice run for familiarisation and subsequently performed the virtual laparoscopic cholecystectomy (LC) once. Among the medical students, they were randomised to either a control or intervention group. They were tasked to perform a second- and third-timed LC assessment. Participants were asked to rate the simulator using a 5-point Likert scale questionnaire. IRAS rated favourably in hand-eye coordination and training bimanual dexterity (mean score: 4.1 and 4.0 among students, 3.4 and 3.4 among residents) though it faired suboptimally in realism. At baseline, residents were statistically faster compared to students (overall time: 418.9 vs 586.8 seconds, *P* = 0.001). Participants randomised to the intervention group consistently scored better. However, their overall time were not statistically significant from the control group. The robotic guidance capability of the IRAS is a key advantage of this simulator platform over the conventional platform.

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Introduction

Surgical traineeship has traditionally been based on a master apprentice model where learning takes place in the operating theatre. This approach has changed significantly with greater emphasis on surgical training taking place within the surgical skills laboratory. Basic laparoscopic handling skills are being taught to surgical trainees using the fundamentals of laparoscopic skills box trainer.[1,2] Virtual reality laparoscopic simulators or cadaveric dissections can further enhance training by allowing users to undertake partial or full surgical procedures.

Virtual reality simulators are currently excellent tools in teaching basic psychomotor and visual-spatial laparoscopic skills.[3] These simulators have improved with increasing realistic anatomy, tactile feedback and software that allows for training on complete laparoscopic procedures.[4] Virtual simulator utilises guidance concerning software involving digital lines or arrows to direct the user to the next step.[5] These teaching adjuncts have been validated to decrease operating time, increase accuracy and improve economy of movement in individuals.[6]

Experienced surgeons have better dexterity. They are able to complete a laparoscopic task faster and with better economy of movement.[7] The manoeuvring of laparoscopic instruments is a difficult aspect for more experienced surgeons to teach surgical trainees. Trainees traditionally learn these manoeuvres through observation and trial and error. Subsequently, the manoeuvring of the laparoscopic

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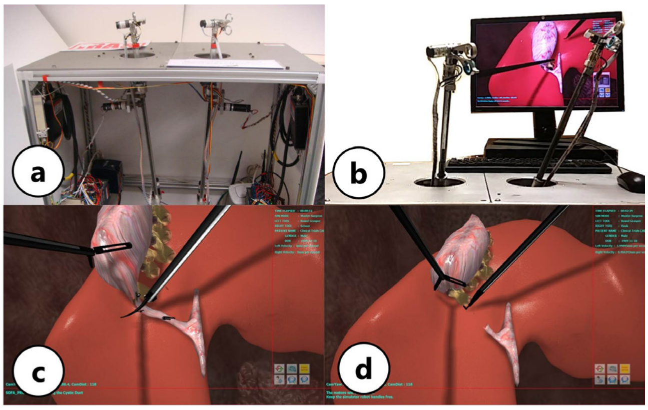

Fig. 1. Image-guided robotic assisted surgical simulator (IRAS). A) Interior setup of the IRAS simulator. B) IRAS setup with external monitor. C) Division of the cystic duct. D) Ablation of connective tissues to free the gallbladder from the liver bed.

instrument is left to the discretion of the trainee. We have sought to address this deficiency with the incorporation of a robotic guidance feature into a high fidelity simulator.[8,9] The robotic guidance feature is functioned to “hand-hold” the user to move in a predetermined route. It is hypothesised that transfer of surgical skills can be further improved with this added capability.

Materials and Methods

Participant Selections

Thirteen surgical residents were recruited from a single institution; 29 medical students who were rotating through the surgical department at the time of the study were also recruited. At recruitment, the 29 medical students were randomised into a control or intervention group. Fifteen were in the control group and 14 were in the intervention group.

Instrument – Image-guided Robotic Assisted Surgical Simulator (IRAS)

The IRAS training system is developed to mimic the process of an experienced surgeon physically holding a trainee's hands to demonstrate movement of the laparoscopic instruments. IRAS consists of 3 major components: medical image processing and model reconstruction module,[10,11] surgical simulation platform,[12,13] and the robotic laparoscopic surgical trainer.[8,9] A simulated surgical procedure can be reproduced for training and demonstration. Motion of the robotic handle and tool-tissue interaction can be replayed on the robot and the surgical simulation platform simultaneously. The user can hold the handles of the moving robotic instruments while watching the simulated surgical procedure to appreciate the manoeuvres performed by an experienced surgeon. Motor skills training is conducted through such a record and replay procedure.

For this study, IRAS was designed to allow participants to perform a virtual laparoscopic cholecystectomy (LC). The procedure involved the ablation of the connective tissue to expose the cystic duct, deployment of clips on the cystic duct, cutting of the cystic duct and ablation of the connective tissue to free the gallbladder from the liver bed (Fig. 1). The time taken and trajectory distance of each subtask was recorded and generated as an assessment report at the end of the procedure. Two different virtual anatomical setups were made. One setup was used for familiarisation with IRAS and the other setup was used for assessment. Additional details of the design and construct of the simulator is described elsewhere.[8,9]

Experimental Task and Protocol

The study was conducted in 2 phases. The first phase involved surgical residents and the second phase involved medical students. Amongst surgical residents, they were given an introduction and allowed one practice run to familiarise themselves to IRAS. Subsequently, they were tasked to perform the virtual LC once. Upon completion, they were showed how the robotic guidance functioned before filling up a questionnaire.

In the second phase, medical students were first given a video introduction to the steps involved in performing a LC. They were then introduced to IRAS and allowed one practice run for familiarisation. Subsequently, they performed an assessment run on the virtual LC which was assigned as their baseline performance.

Participants were randomly allocated to either control or intervention group in a 1:1 ratio using a block randomisation technique. The allocation of intervention options to each numbered envelope was computer generated based on a block randomisation with block size of 10. Control participants were given 10 minutes of self-practice followed by a second-timed assessment. Participants in the intervention group underwent training only via the robotic guidance mode for 10 minutes followed by a second-timed assessment. This cycle of training and assessment was performed till all the participants completed a total of 3 timed assessments. The robotic guidance playback was based on the recording from a surgical consultant. A 5-point Likert questionnaire was then administered (Table 1).

Statistical Analysis

Sample size calculation was based on a priori power analysis. As incorporation of robotic guidance is novel, we looked at previous studies that compared deliberate practice training against routine training. The improvement effects in such studies ranged from 20%-35%.[14,15] We calculated our sample size based on detecting at least a 20% difference in surgical performance with alpha of 0.05 and beta of 0.8.

In phase 1, we needed a minimum of 10 surgical residents and 10 medical students. In phase 2, we needed

Table 1. Questions of the 5-Point Likert Scoring Questionnaire

Questions	**Responses**
Preliminary questions	
Age & gender	
Dominant hand	1) Right 2) Left
Past experience with training with low fidelity surgical trainer (i.e. surgical box trainer)?	1) Limited experience (used for days to weeks) – attended laparoscopic course 2) No previous experience 3) Vast experience (used for weeks to months) – repeated usage of a surgical box-trainer
Past experience with training with high fidelity surgical trainer (i.e. surgical simulators)?	1) Limited experience (used for days to weeks) – attended laparoscopic course 2) No previous experience 3) Vast experience (used for weeks to months) – repeated usage of a surgical simulator
Current level of training? (residents) Which year of medical school are you currently in? (medical students)	
How many years of training/rotating through general surgery?	
Past experience with laparoscopic surgery? (residents) I have watched laparoscopic surgeries in the operating theatre before? (medical students)	
Past experience with laparoscopic cholecystectomy? (residents) I have watched laparoscopic cholecystectomy in the operating theatre before? (medical students)	
I feel that surgical simulators should be incorporated into my training?	1 – Strongly disagree, 2 – Disagree, 3 – Neutral, 4 – Agree, 5 – Strongly agree
Design & functionality	
I like the appearance and design of the simulator setup?	1 – Strongly disagree, 2 – Disagree, 3 – Neutral, 4 – Agree, 5 – Strongly agree
I like the appearance and design of the virtual reality environment?	
I feel that IRAS is user friendly?	
The movement of the laparoscopic instruments was well reflected in the virtual reality environment?	
The virtual reality environment/graphics look similar to real-life operation?	
The movement of the laparoscopic instruments in the virtual reality environment feels similar to real-life operation?	
The application of clips in the virtual reality environment feels similar to real-life operation?	
The cutting function in the virtual reality environment feels similar to real-life operation?	
The dissection of the gallbladder from the bed of the liver feels similar to real-life operation?	
Training capabilities	
IRAS is a useful instrument to train basic laparoscopic skills to residents?	1 – Strongly disagree, 2 – Disagree, 3 – Neutral, 4 – Agree, 5 – Strongly agree
IRAS is a useful instrument to train laparoscopic procedures (i.e. laparoscopic cholecystectomy) to residents?	
IRAS is a useful instrument to train hand-eye coordination?	
IRAS is a useful instrument to train depth perception in laparoscopic surgery?	
IRAS is a useful instrument to train bimanual dexterity in laparoscopic procedures?	
The addition of the robotic guidance mode will enhance the training capability of the simulator?	
Surgical simulators are superior to basic laparoscopic box trainer in training laparoscopic skills?	
Surgical simulators should be incorporated into surgical education?	
I will benefit from using the IRAS simulator?	
I feel that the overall experience of performing a virtual laparoscopic cholecystectomy is realistic?	

IRAS: Image-guided Robotic Assisted Surgical Simulator a minimum of 10 medical students in each of the study arm. We aimed to recruit up to 15 surgical residents and 30 medical students (15 in each arm) to account for potential exclusion of participants. We were aware that technical errors within the IRAS system exist which could lead to missing data. Analyses between the various groups of participants were compared using non-parametric analysis (Mann-Whitney U test). We presented time and trajectory distances as medians. An exact significance (2-tailed) *P* value of ≤0.05 was considered significant. All statistical analyses were performed using the SPSS version 20.0 (SPSS, Inc., Chicago, IL).

Results

Assessment between Surgical Residents and Medical Students

Owing to missing or incomplete data capture, the final analysis included 9 surgical residents and 24 medical students. At baseline, surgical residents were statistically faster compared to medical students (dissection time: 73.5 vs 163.4, *P* = 0.01 and overall time: 418.9 vs 586.8 seconds, *P* = 0.001). Surgical residents were faster in all the other domains of exposure time, clipping time, cutting time and performed the procedure with a shorter trajectory distance. However, the results did not reach statistical significance (Table 2).

Assessment of Robotic Guidance

The final analysis included 12 participants in the control group and 11 in the intervention group. We presented data on dissection time, overall time and overall trajectory distance. At baseline, there were no significant differences in the control and intervention group (Table 3). In the subsequent second and third assessments, participants in both groups had improvement in time taken as well as the trajectory distance. Participants randomised to the intervention group had statistically significant improvement in dissection time (second run) and trajectory distance (right instrument, third run) (Table 3).

Subjective Feedback on IRAS

A 5-point Likert scoring questionnaire was used to assess the realism of IRAS and its usefulness as a teaching modality (Table 1). The questions related to realism of IRAS were assigned only to the surgical residents as they had prior operating theatre experience with laparoscopic surgery. For realism, IRAS was rated suboptimally with scores less than 3. As a teaching adjunct, IRAS rated favourable in hand-eye coordination as well as training bimanual dexterity. Medical students rated IRAS more favourably as compared to surgical residents (Table 4).

Discussion

The technique of manoeuvring laparoscopic instrument in performing a procedure is difficult to learn without feedback.[16] The concept of teaching laparoscopic surgery via robotic guidance playback is novel and not previously validated in the literature. Our study is a pilot project in evaluation of robotic guidance in surgical training. From our analysis, we have 2 key findings. First, IRAS is able to discriminate between users of varying surgical experience level. Secondly, transfer of laparoscopic skills can be achieved through robots.

Evaluation of IRAS between Surgical Residents and Medical Students

In the first phase of our study, we determined that IRAS could discern between users of varying surgical experience. When compared based on dissection time and overall time, surgical residents achieved a significant difference compared to medical students (Table 2). IRAS's inability to discriminate the time difference in the other domains could be attributed to the simulator's lack of realism. In real-life laparoscopic cholecystectomy, the challenge involves the complete skeletonisation of the cystic duct. The grasper is used for manipulation of the infundibular junction while the hook cautery performs the dissection. In contrast, IRAS lacks bleeding, has poorly deformable organ structure

Table 2. Baseline Performance between Surgical Residents and Medical Students

Baseline	**Surgical Residents**	**Medical Students**	***P* Value (Residents vs Medical Students)**
Exposure time (s)	60.2 (27.0), n = 11	85.3 (66.1), n = 28	0.078
Clip time (s)	125.4 (89.6), n = 11	173.6 (179.0), n = 28	0.149
Cut time (s)	28.0 (21.1), n = 11	44.5 (30.9), n = 28	0.078
Dissection time (s)	73.5 (67.0), n = 9	163.4 (106.9), n = 25	0.010*
Overall time (s)	418.9 (111.9), n = 9	586.8 (225.6) , n = 24	0.001*
Overall trajectory (right)	3385.9 (1628.4), n = 9	4486.6 (2582.9), n = 23	0.246
Overall trajectory (left)	3837.8 (1204.4), n = 9	4289.3 (1961.2), n = 23	0.133

*Statistically significant results.

Table 3. Performance between Medical Students who Trained Without and With Robotic Guidance

	Control Group (Conventional Simulator Training)	Intervention Group (Robotic Guidance Training)	*P* Value (Control vs Intervention)
Baseline Run			
Dissection time (s)	168.6 (118.3), n = 13	139.0 (77.5), n = 11	0.303
Overall time (s)	618.1 (251.0), n = 13	510.5 (181.3), n = 11	0.303
Overall trajectory (right) mm	4497.7 (3012.2), n = 12	4273.6 (2004.6), n = 11	0.487
Overall trajectory (left) mm	4567.9 (2178.7), n = 12	4486.6 (1586.7), n = 11	0.211
Second Run			
Dissection time (s)	152.9 (96.0), n = 14	115.4 (78.1), n = 13	0.038*
Overall time (s)	486.9 (223.5), n = 14	372.2 (211.9), n = 13	0.458
Overall trajectory (right) mm	3848.4 (3739.4), n = 14	2875.3 (1908.3), n = 14	0.114
Overall trajectory (left) mm	4014.3 (2334.6), n = 14	3162.2 (1759.8), n = 14	0.427
Third Run			
Dissection time (s)	115.8 (43.2), n = 12	88.6 (75.2), n = 11	0.059
Overall time (s)	357.5 (117.5), n = 13	261.0 (160.3), n = 11	0.063
Overall trajectory (right) mm	3617.1 (1289.1), n = 12	2186.3 (2153.2), n = 11	0.032*
Overall trajectory (left) mm	3382.8 (1218.0), n = 12	2906.0 (1602.6), n = 11	0.260

*Statistically significant results.

Table 4. Subjective Assessment of IRAS

Domains	Residents n = 14	Students n = 29
Hardware appearance	3.1 (1.0)	3.7 (0.9)
Software appearance	2.8 (1.0)	3.3 (1.1)
User-friendliness	2.9 (1.0)	3.1 (1.0)
Movement of virtual laparoscopic instruments	2.3 (1.0)	2.9 (1.0)
Graphic realism	2.4 (0.8)	NA
Movement realism	2.5 (1.2)	NA
Realism of clipping	2.6 (1.2)	NA
Realism of cutting	2.6 (1.2)	NA
Realism of dissection	2.4 (1.0)	NA
Teaching basic laparoscopic skills	3.1 (1.2)	3.8 (0.9)
Teaching laparoscopic procedures	3.1 (1.2)	3.7 (0.8)
Training hand-eye coordination	3.4 (1.2)	4.1 (0.8)
Training depth perception	3.2 (1.2)	3.1 (1.2)
Training bimanual dexterity	3.4 (1.1)	4.0 (0.8)
Benefit of robotic guidance	2.9 (1.1)	3.6 (0.8)
Recommend to trainees	3.9 (0.9)	NA
Incorporating surgical simulators into surgical education	3.7 (1.0)	4.1 (0.6)
Interest in general surgery (before)	NA	3.1 (1.4)
Interest in general surgery (after)	NA	3.7 (0.9)

IRAS: Image-guided Robotic Assisted Surgical Simulator; NA: Not applicable

and rudimentary Calot's dissection. Due to technical limitations, the cystic artery was also not included in the current simulator design. The IRAS simplifies ablation of a portion of connective tissues to a touch by the hook cautery instead of plane identification. Additionally, the movement of the instruments felt crude in the hands of the surgical residents. This would have interfered with the assessment.

Transfer of Laparoscopic Skills

Nevertheless, we have shown that surgical laparoscopic skills can be taught via robotic guidance. The robotic guidance that the participants had was based on a recorded version of an experienced surgeon's performance on the IRAS. They were trained repeatedly with that recorded version during their 10 minutes of allocated training time. While robotic guidance training trended towards improved overall timing, we currently do not observe a statistical difference in overall time (Table 3 and Fig. 2).

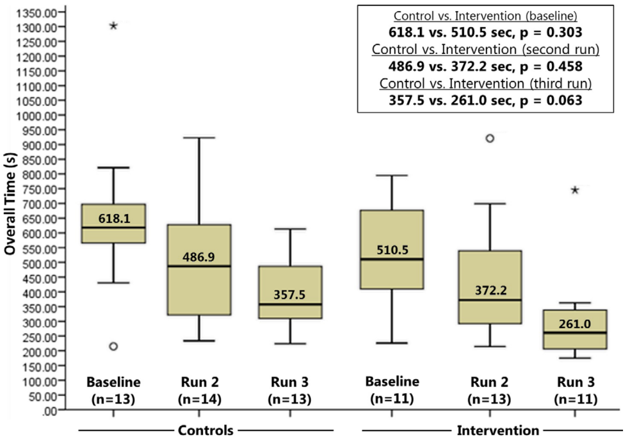

Fig. 2. Graph showing the overall time between the control and intervention group for baseline, run 2 and run 3 assessments.

The most complex subtask in the current model would be the dissection of the gallbladder away from the liver bed. Participants were required to use one instrument to control the position of the gallbladder with the second instrument positioned to ablate the connective tissue. This subtask did achieve statistical significance in the intervention group compared to the control group (Table 3). Additionally, overall trajectory distance also achieved statistical significance by the third (3617.1 mm vs 2186.3 mm, $P = 0.032$). With robotic guidance, participants could have learned how to rightly manoeuvre both the instruments to achieve quicker dissection and more precise movements compared to a trial-and-error approach.

Benefits and Limitations of Robotic Guidance

The robotic guidance function may inadvertently put forth the misconception that there is only one right way to perform a surgical procedure. In real-life, many different surgical techniques exist. The type of technique also differs based on the anatomy encountered. With increased surgical experience, most surgeons do develop their own technique in dealing with a challenging anatomy. At present, the lack of realism in IRAS impedes the potential benefits of the robotic guidance. We anticipate that with a highly realistic simulator model, the robotic guidance would be best used to teach specific aspects of a surgery (i.e. bowel wall suturing, Calot's dissection).

Study Limitations

The current study is limited by the low number of training cycles (2 x 10 minutes block). Increased training cycles might help to further differentiate between the control and the intervention group. Additionally, we have yet to investigate if the learning effects of robotic guidance training can be retained. The incorporation of simulator-based training with assessment on a cadaveric porcine model would have given a better indicator on the usefulness of the robotic guidance in terms of skill transfer.

Nevertheless, the results of this study suggest that incorporation of robotic guidance is a useful adjunct for next-generation laparoscopic simulators. It is likely that with a more realistic simulator platform, the capabilities of the robotic guidance function will be more evident.

Conclusion

Virtual reality simulation training will continue to be an important adjunct for training surgical residents in laparoscopic surgery. Next-generation simulators can consider the incorporation of robotic guidance to their setup to enhance the user's learning experience.

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